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A Review of Research on the Laser Marksmanship Training System

Monte D. Smith
L-3 Communications

Joseph D. Hagman
U.S. Army Research Institute

20010405 024

Reserve Component Training Research Unit
Ruth H. Phelps, Chief

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14. ABSTRACT *(Maximum 200 words)*: This report reviews research on use of the Laser Marksmanship Training System (LMTS) to support small-arms marksmanship training and live-fire performance prediction. In general, the findings to date indicate that (a) an LMTS-established rifle battlesight zero should not be used for record fire qualification without prior live-fire zero confirmation, (b) LMTS is capable of supporting effective initial entry, as well as sustainment, rifle marksmanship training although further research is needed to provide a definitive conclusion in regard to the latter, (c) LMTS-based performance can accurately predict the likelihood of both rifle and pistol live-fire qualification, and (d) these predictions provide an associated set of empirically derived, live-fire performance standards needed to support the implementation of competency-based small-arms training with LMTS as well as the use of LMTS for validating previous live-fire qualification performance when outdoor range facilities are not readily available or when mission requirements dictate.

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A REVIEW OF RESEARCH ON THE LASER MARKSMANSHIP TRAINING SYSTEM

EXECUTIVE SUMMARY

Requirement:

To review research on use of the Laser Marksmanship Training System (LMTS) to support small-arms marksmanship training and live-fire performance prediction.

Procedure:

Reviewed research examined (a) the correspondence between an LMTS- and live-fire-established rifle (M16A1/A2) battlesight zero, (b) LMTS capability to support rifle marksmanship sustainment training, (c) the relative effectiveness of LMTS-based vs traditional Basic Rifle Marksmanship (BRM) training, (d) statistical models for predicting rifle and pistol (M9) live-fire marksmanship scores from LMTS-based performance, and (e) development of weapon-specific, LMTS-based tools for predicting the likelihood of soldier live-fire qualification.

Findings:

An LMTS-established zero was found not to correspond to a live-fire-established zero for most (73%) rifles tested. Use of LMTS was found, however, to support effective sustainment training and produce superior initial entry BRM performance relative to that achieved under the traditional training approach. The statistical relations found between LMTS and live-fire performance for both rifle and pistol were strong enough to support development of weapon-specific tools for predicting the likelihood of individual soldier, first-run, live-fire qualification based on LMTS scores.

Use of Findings:

These findings indicate that (a) an LMTS-established rifle battlesight zero should not, as yet, be used for record fire qualification without prior live-fire zero confirmation, (b) LMTS is capable of supporting effective initial entry, as well as sustainment, rifle marksmanship training although further research is needed to provide a definitive conclusion in regard to the latter, (c) LMTS-based performance can accurately predict the likelihood of both rifle and pistol live-fire qualification, and (d) these predictions provide an associated set of empirically derived, live-fire performance standards needed to support the implementation of competency-based small-arms training with LMTS as well as the use of LMTS for validating previous live-fire qualification performance when outdoor range facilities are not readily available or when mission requirements dictate.

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Introduction

The delivery of basic small-arms marksmanship training has been a challenge for the U.S. armed forces since the days of the Continental Army (Government Accounting Office Report to Congressional Committees, 1995). Despite modern weaponry and an accumulated body of time-tested training methods (Evans, Dyer, & Hagman, 2000), the challenge today seems no less formidable than at any time in the past. Budget cuts, coupled with increased ammunition costs and reduced access to live-fire ranges, have all but mandated the use of cutting edge technology to meet current marksmanship training standards (Krug & Pickell, 1996). In the Reserve Component (RC), budget cuts and range access problems are exacerbated by ever-present training time constraints (Hagman & Phelps, 1999), plus the necessity for conducting most training at home station where live-fire range facilities are often not readily available.

These considerations have prompted the U.S. Army Reserve (USAR) to search for more effective and efficient ways to train and evaluate small arms marksmanship through the use of training devices (San Miguel, 1998). The objective of this search is the development and evaluation of indoor (i.e., home station), device-based rifle and pistol marksmanship sustainment training programs that will produce proficiency levels that meet or exceed unit readiness requirements while minimizing the resources needed to do so (Plewes, 1997, Oct 9). This objective is currently being pursued through a partnership involving the U.S. Army Research Institute (ARI) and the U.S. Army Reserve Command's (USARC's) marksmanship executive agent (i.e., the 84th Institutional Training Division [DIVIT]) and Small Arms Training Team (SATT).

Based on a relative capabilities analysis of candidate training devices conducted by USARC (Memorandum for Record, 1997, Dec 14), the device selected to support small arms marksmanship training is the Laser Marksmanship Training System (LMTS; BeamHit™, 1999). LMTS is a laser-emitting device, designed for indoor use, which enables targets to be engaged with Army-issue weapons without the use of live ammunition. Different applications of LMTS have been developed for rifle (M16A1/A2) and pistol (M9). The major components of each include a laser transmitter, a mandrel to which the transmitter is attached/aligned, a variety of laser sensitive targets, and a dedicated computer with optional printer (Figure 1). One end of the mandrel holds the laser transmitter and the other end slips into the barrel of the weapon. For both rifle and pistol, vibrations from the weapons' (mechanical) firing mechanism activate the laser when the weapons are dry fired, and the location of the emitted beam is first "picked up" by the laser-sensitive target(s) (Dulin, 1999). Those connected to a computer enable the recording and storage of performance data for future analysis and printout. Other freestanding targets provide immediate feedback by counting or depicting target hits.

Current plans call for using LMTS technology to develop device-based rifle and pistol marksmanship sustainment training programs that will accomplish the following: (a) train marksmanship fundamentals for rifle (steady position, aiming, breath control,

and trigger squeeze) and pistol (grip, aiming, breath control, trigger squeeze, target engagement, and firing position), as well as support the training of shot grouping and weapon battlesight zeroing procedures associated with the former, (b) ensure training produces proficiency levels that are equal to, or greater than, those produced by traditional training methods, and (c) develop an LMTS-based rifle marksmanship Alternate Qualification Course (ALT-C; Headquarters, Department of the Army,1989) and an LMTS-based Alternate Pistol Qualification Course (APQC; Headquarters, Department of the Army, 1988) that will identify soldiers most in need of sustainment training, signal when enough such training has been provided, and permit LMTS-based qualification firing as a validation of previous live-fire qualification firing when outdoor range facilities are not readily available or as mission requirements dictate.

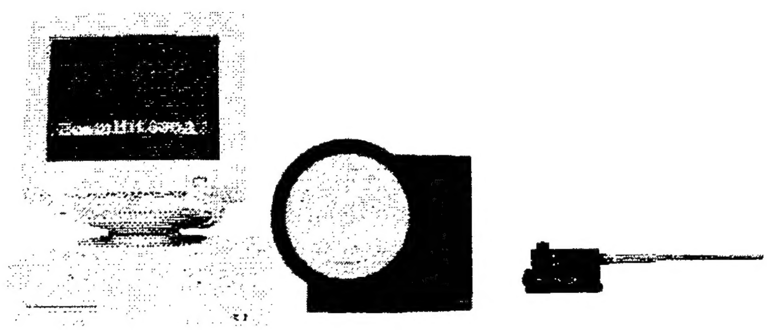

Figure 1. LMTS computer/monitor, sample electronic target, and laser transmitter with attached mandrel.

Some of the above objectives have already been met. Others are currently under development or are being planned. Both rifle (Commander, SATT, 1999a) and pistol (Commander, SATT, 1999b) programs of instructions (POIs), for instance, have been developed. The rifle POI has undergone field testing (Smith, 2000) to evaluate its capability for supporting realistic and comprehensive marksmanship sustainment training while also screening for soldiers in need of remediation. The pistol POI, in contrast, has yet to be formally evaluated, although it closely parallels the rifle POI in both procedure and content and is expected to deliver comparable results. Moreover, several investigations have been conducted to determine whether or not an LMTS-based rifle zero can be substituted for that established using live ammunition (Hagman & Smith, 1999).

LMTS also has been tested at Fort Benning, GA, (Smith & Hagman, 2000) as an alternative to traditional devices (i.e., the dime [washer], target [shadow] box, MACS, and the Weaponeer) in the training basic rifle marksmanship (BRM). This research examined not only training effectiveness, but also training efficiency in the form of possible ammunition savings during subsequent live-fire shot grouping and weapon zeroing exercises following completion of LMTS-based training.

The most recent LMTS investigations (Smith & Hagman, 2000) have sought to determine the degree of correspondence between device- and live-fire-based tests of marksmanship for both rifle and pistol versions of LMTS. An empirically based relation

between device-and live-fire-based marksmanship performance is a prerequisite for identifying soldiers most in need of sustainment training (i.e., unlikely live-fire qualifiers), determining when sufficient sustainment training has been provided (i.e., when the likelihood of live-fire qualification is good), and predicting live-fire qualification results based on scores fired with LMTS. This line of research has recently resulted in LMTS-based, live-fire prediction models for both rifle and pistol.

Other research on LMTS, such as an examination of its long-term benefits and further determination of its relative effectiveness (when compared to that obtained via traditional marksmanship training methods), is either underway or in the planning stages. The remainder of this report reviews and summarizes the LMTS research that has been completed to date as part of the ARI/USAR partnership, and suggests areas for future research.

Rifle Zeroing with LMTS

One of the first questions to be asked about LMTS was whether it could be used to establish a weapon zero that did not require live-fire confirmation (Hagman & Smith, 1999). If so, an LMTS-established zero could take the place of a live-fire-established zero and the time and ammunition usually required to live-fire zero before qualification firing could be eliminated. USAR units typically devote one drill weekend each year to marksmanship training and qualification firing, with most of the latter's time taken up by the grouping and zeroing process to ensure that weapons fire where aimed. If these weapons could be zeroed with LMTS during training and then carried to the range without the need for follow-up live-fire confirmation, then range time could be freed up for the conduct of other mission-related activities during drill. A three-phased research effort examined the feasibility of this notion.

Validity of an LMTS-Established Zero

The substitutability of an LMTS-established zero for a live-fire-established zero was examined at Fort McClellan, AL (Hagman & Smith, 1999). One set of M16A2 rifles was zeroed with live ammunition on an outdoor 25m live-fire range while another set was zeroed indoors using LMTS. All weapons were then fired with live ammunition on the outdoor range to (1) determine the validity of the LMTS-established weapon zero, and (2) compare the confirmation rate achieved under the two zeroing procedures, with the live-fire-to-live-fire confirmation rate serving as the standard against which to judge the relative success of the LMTS-based zeroing process.

Eighty percent of weapons in the live-fire-to-live-fire condition received confirmed zeroes during confirmation firing, whereas the zero was confirmed on only 32% of weapons initially zeroed with LMTS. The difference between 80% and 32% was statistically significant. Moreover, on the average, live-fire-zeroed weapons fired significantly more rounds within the zero target circle (5.3 out of a possible 6) than those fired from LMTS-zeroed weapons (2.3 out of a possible 6).

Alternative Laser Calibration Procedures

In a follow-up investigation, conducted at Fort Benning, GA, a manufacturer-recommended alternative laser calibration procedure was tested to determine if improper laser calibration might have produced the relatively low LMTS-based zero confirmation rate obtained at Fort McClellan. It was hypothesized that an inadvertent bias might have been introduced by the manner in which laser transmitters had been positioned in the muzzles of weapons. In the earlier investigation, mandrels were inserted into the barrel, three laser rounds were fired at the target, and these laser impact points were then used to calculate a laser centroid, using a mathematical centering algorithm programmed into the LMTS computer. This centroid was then used as the aiming point against which to adjust weapon sights during the zeroing process.

In this second investigation, the transmitter mandrel was positioned (rotated) at 0, 90, 180, and 270 degrees with three laser rounds fired at each location. The same mathematical centering algorithm was then used to calculate the laser centroid, and subsequent sight adjustments using this (presumably more stable and accurate) aiming point were made during the zeroing process. It was expected that this more exhaustive calibration procedure would help stabilize laser centroids, reduce discrepancies between the calculated laser aiming point and subsequent bullet strike location, and consequently produce a higher rate of LMTS to live-fire zero correspondence.

The LMTS-based zero confirmation rate obtained in this second investigation, however, was even lower than that found in the first. After testing five rifles, the live-fire confirmation rate was 0%. Moreover, an average of only two out of a possible six live-fire rounds landed within the zero target circle. This number was statistically comparable to that obtained with LMTS-zeroed weapons in the first investigation. The LMTS-based zero confirmation rate subsequently obtained with "match" grade weapons (i.e., those normally reserved for competition use) was higher (60%, with an average of 4.4 live round circle hits), but match grade weapons are not ordinarily available for training or qualification purposes. Thus, it was concluded that the more elaborate rotational calibration procedure did not improve the LMTS-based zero confirmation rate or the associated number of circle hits, at least for the grade of weapon typically issued for qualification firing.

Laser Beam Aiming Point vs Bullet Strike Location

The third investigation (Hagman & Smith, 1999) also focused on determining why LMTS-based zeroes did not correspond to live-fire-based zeroes. A weapon stabilization cradle (Figure 2) was used to remove all shooter variation effects. It was reasoned that under conditions of weapon stabilization, laser beam aiming point should be identical (within ammunition dispersion tolerances) to bullet strike location. If the two locations failed to correspond, then the low LMTS-based zero confirmation rates in the first two investigations could be explained as byproducts of incorrect LMTS laser beam aiming points. If laser beam and live-fire impact points still differed under conditions of weapon

stabilization, substitutability of LMTS-based zeroes for live-fire zeroes could not be recommended.

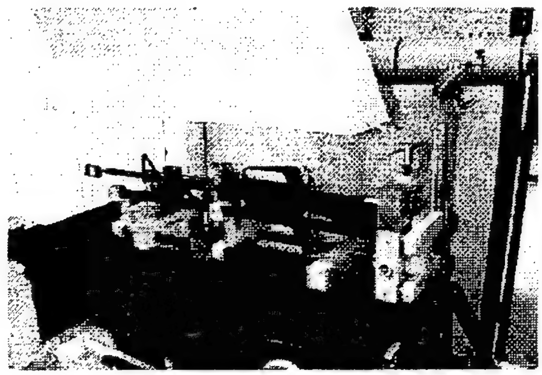

Figure 2. Weapon stabilization cradle.

Results indicated that although lasers and bullets both produced their own distinct clusters, these clusters were typically at different locations on the targets, notwithstanding the fact that all rifles were immobilized during both laser and live-fire ammunition firing. When targets were placed at 25m, the mean distance from laser centroids to bullet centroids was 42.9mm, a distance that was significantly greater than the observed live ammunition dispersion/variability benchmark of 21.2mm. These findings explain, at least in part, the relatively low zero confirmation rates found in the first two investigations. In essence, during these two data collection efforts, weapon sights had been adjusted during zeroing to coincide with an errant aiming point provided by LMTS.

Implications of Zero Noncorrespondence

The conclusion drawn from the first series of investigations was that LMTS-established zeroes did not precisely correspond to, and thus could not be substituted for, live-fire-based zeroes. It was recommended that USAR soldiers should not attempt record fire qualification with an LMTS-zeroed weapon without first confirming this zero with live ammunition. Investigators hastened to add, however, that because LMTS was designed as a training device and not a zeroing device, its inability to establish a weapon zero that would eliminate the need for subsequent live-fire confirmation in no way compromised the potential use of LMTS for training purposes, nor did it preclude the potential use of the device for live-fire performance prediction purposes.

Moreover, they suggested that although device- and live-fire-based zeroes could not be substituted, it was nonetheless likely that some range time and ammunition savings would result from the firing of LMTS-zeroed weapons. Although laser beam aim point did not correspond exactly to bullet impact location, the two centroids were close enough to ensure that bullets impacted in the general vicinity of the laser aim point. For example, all live rounds fired from LMTS-zeroed weapons during live-fire zero confirmation in the first two investigations landed within the grid area of the zero target, thereby providing a reference for subsequent sighting adjustments. Moreover, based on combined results from the first two investigations, 27% of rack grade weapons indeed had confirmable

live-fire zeroes and, therefore, would have required no additional sight adjustments prior to qualification firing. Thus, for about a quarter of all weapons carried to the range in the future, the time ordinarily required to live-fire zero on the range would be reduced (by not requiring subsequent sight adjustments after the firing of initial zero confirmation rounds), thereby streamlining the overall qualification process. The manufacturer (i.e., BeamHit^{TM}) of LMTS has since made improvements in laser and mandrel design that may warrant further investigation into the zeroing capabilities of LMTS.

Perhaps the most significant advantage of grouping and zeroing with LMTS during training is that soldiers who have already completed this training will arrive at the live-fire range with the basic concept and procedural steps already mastered and, thus, be better able to optimize their time on the live-fire range.

The Fort Indiantown Gap Investigation

While the technical limitations of LMTS technology were being explored at Forts McClellan and Benning, other research was serving to evaluate the USAR's LMTS-based rifle marksmanship sustainment training program and to develop the LMTS version of the 25m ALT-C (Headquarters, Department of the Army, 1989) test of rifle marksmanship. The full training package for the M16A1/A2, including the newly developed POI (Commander, SATT, 1999a), was ready for evaluation in August, 1999, with the 319th Engineer Company (Butler, PA) of the 458th Engineer Battalion (99th Reserve Support Command [RSC]) during Annual Training (AT) at Fort Indiantown Gap, near Harrisburg, PA (Smith, 2000). All participating soldiers were equipped with M16A2 weapons. Instructors consisted of 10 commissioned and noncommissioned officers (NCOs) from the 84th DIVIT and SATT. The principal objectives of this effort were to test LMTS's ability to (a) support the newly developed rifle marksmanship POI, (b) identify soldiers in need of remedial training and to deliver that needed training as part of the POI prior to firing for record, (c) support effective sustainment training of rifle marksmanship as reflected in improved record fire qualification scores, and (d) predict first run live-fire qualification scores based on LMTS ALT-C performance.

The Fort Indiantown Gap effort was part of a larger coordinated sequence of data collection efforts, designed to make use of reserve units as they became available for research participation. (The full research design is presented and discussed in Appendix A.) At Fort Indiantown Gap, all participating soldiers completed LMTS-based training followed by LMTS ALT-C firing. The next day, soldiers fired the ALT-C with live ammunition. Of particular interest was the proportion of soldiers achieving live-fire qualification after having received LMTS training, and the relation between LMTS ALT-C and live-fire ALT-C scores.

Except for the substitution of laser beams for bullets, LMTS and live-fire ALT-Cs were identical, both in compliance with FM 23-9 [Headquarters, Department of the Army, 1989] stipulated procedures. On both tests, scores could range from 0 to 40, with a minimum of 26 required for qualification as a Marksman, 33 for Sharpshooter, and 38 for Expert. Unless specifically noted to the contrary, analyses of LMTS and live-fire

ALT-C scores in this and in all subsequent investigations refer to first run scores (Q1), that is, scores obtained by soldiers on their first qualification attempt.

LMTS POI

The basic element of LMTS-based M16A1/A2 marksmanship training is its POI (Commander, SATT, 1999a), which closely follows FM 23-9 (Headquarters, Department of the Army, 1989) stipulated procedures, including weapon familiarity drills, immediate-action procedures, loading and unloading magazines, front and rear sight adjustments, application of the four fundamentals of marksmanship (steady position, aiming, breath control, and trigger squeeze), interactive dry firing, battlesight zeroing, and detecting and engaging a variety of targets. LMTS also permits grouping and zeroing as part of the POI. Remedial training is provided on an as-needed basis as part of the POI. The concluding exercise (for all soldiers) is a timed record fire engagement on the LMTS ALT-C, using laser-equipped weapons and laser-sensitive targets. In addition to the POI original source document (Commander, SATT, 1999a), a more detailed account of the POI's implementation at Fort Indiantown Gap is contained in Appendix B.

Operational Constraints

All LMTS-based firing was done under the dry-fire method. Under this method, the carrier bolt is not automatically recycled by escaping gas on an LMTS-equipped M16 rifle, therefore, the soldier is required to manually re-cock the weapon after each round by recycling the charging handle located at the rear of the upper receiver assembly. This is a simple step for the soldier to accomplish, requiring a charging handle movement of only a little more than an inch.

Although LMTS was designed specifically for indoor use, suitable indoor facilities were not available during the Fort Indiantown Gap evaluation. Therefore, all elements of the LMTS POI, including the LMTS ALT-C, were conducted outdoors.

Results

Remedial Training. Almost two-thirds (63.9%) of participating soldiers underwent LMTS-based remedial training. It was not possible to assess experimentally the effectiveness of this training because it was given to every soldier identified as needing it. (An experimental assessment of its effectiveness would have required that remedial training be withheld from some soldiers.) However, soldiers identified as needing remedial training are by definition deficient in one or more marksmanship fundamentals. At the end of training, soldiers who had received remedial training did not differ from soldiers not receiving remedial training on any objective marksmanship performance measure, lending support to the notion that remedial training was successful.

Training effectiveness. Based on 83 soldiers who completed all phases of the investigation, live-fire ALT-C hit scores averaged 29.86 (out of a possible 40). Over three-fourths of soldiers (75.9%) fired the minimum Marksman cutoff of 26 points on

their first qualification attempt. An additional 14 soldiers qualified on their second or third attempts, bringing the eventual qualification rate to 92.8%.

Although individual soldier first-run qualification scores from the prior year were not available, battalion records indicated that the eventual qualification rate for the unit had been 63.6%. Unfortunately, the battalion had fired for record the previous year on a pop-up target course, rather than on the stationary, distance-scaled target ALT-C. Thus, the rather dramatic increase in marksmanship qualification rate (from 63.6% to 92.8%) following LMTS-based training could not be interpreted unambiguously because of the range differences that existed from one year to the next. Thus, the improved qualification rates under the LMTS-based POI suggest, but do not necessarily prove, the effectiveness of this training.

Correlation between LMTS and live-fire ALT-C scores. The obtained relation, $r(83) = .16$, was statistically nonsignificant. The most plausible explanation advanced to explain this outcome was that data integrity, to some unknown extent, might have been compromised by the outdoor setting in which LMTS training (and ALT-C firing) was conducted. LMTS was designed specifically for indoor use, and yet, because of unforeseen circumstances, all LMTS-based training and testing had been conducted outdoors.

Conclusions and Lessons Learned

Based on Fort Indiantown Gap results, the USAR's LMTS-based sustainment training program appeared fully capable of supporting a realistic and comprehensive rifle marksmanship POI. It embodied high degrees of perceived face validity and realism, observed and reinforced firearms safety precepts, and readily garnered endorsements from participating soldiers. These positive outcomes occurred notwithstanding last-minute developments that necessitated conducting the POI outdoors. LMTS technology, of course, was designed and is intended for use indoors. Although there was precedent for its use outdoors, neither its manufacturers, nor the USAR training team recommends outdoor usage of LMTS unless lighting conditions are carefully controlled by the use of tents or other overhead cover. It was, therefore, concluded that outdoor use in this instance might have compromised the relation between LMTS and live-fire measures.

The LMTS-based training program was also highly successful in identifying soldiers in need of remedial training and no less so in permitting the delivery of this training (through LMTS technology) as part of the POI. The investigation was not fully successful, however, in demonstrating an improved record fire qualification rate following LMTS-based training. This objective was undermined by an uncontrolled methodological problem (i.e., different types of firing ranges) and was not the fault of the LMTS-based training model.

The biggest disappointment from Fort Indiantown Gap was undoubtedly that the expected empirical relation between LMTS and live-fire scores did not materialize. Without a successful demonstration of this relation, LMTS's utility in predicting live-fire

performance would be seriously compromised. Pursuant to providing a fair and rigorous test of the LMTS-to-live-fire relation, investigators recommended at the conclusion of the Fort Indiantown Gap investigation that future LMTS-based training and testing should be conducted only in suitable indoor settings. They also recommended that availability of prior year ALT-C scores should be a prerequisite for unit participation in future data collection efforts.

The Bangor Investigation

The LMTS-based marksmanship sustainment training program was tested for a second time in late 1999 with 65 USAR soldiers from Company A, 1/391st Regiment and 2/304th (Bangor, ME), 7th Bde (TS), 98th DIVIT during a training weekend at the Army Reserve Training Center on Hildreth Street in Bangor, ME. All soldiers were equipped with M16A1 weapons. Instructors consisted of 11 officers and NCOs from the 84th DIVIT and SATT. Participating units were required to provide prior year individual soldier qualification scores, and this qualification firing had to have been conducted on an ALT-C course. Procedures were the same as at Fort Indiantown Gap except that all training sessions were conducted indoors. In common with the Fort Indiantown Gap investigation, soldiers used their own weapons during all LMTS training phases (including simulated ALT-C firing), fired all LMTS rounds using the hand-charging procedure described in the Fort Indiantown Gap investigation, and then went to the live-fire range for qualification firing.

Results

Remedial Training. Fifty-five of the 65 participating soldiers (84.6%) received remedial training at some point during the LMTS phase of the investigation. This proportion was even higher than at Fort Indiantown Gap, but in common with that earlier investigation, there were no significant differences on any objective performance measure between soldiers who received remedial training and those who did not, again suggesting that the delivered training had produced a beneficial impact.

Training effectiveness. The mean ($N = 65$) first round live-fire ALT-C hit score was 31.78, slightly higher than the Fort Indiantown Gap mean (29.86). Over four-fifths (83.1%) of soldiers achieved the minimum Marksman cutoff of 26 points on their first qualification attempt. An additional 5 soldiers qualified on their second attempt, bringing the eventual qualification rate to 90.8%, a rate comparable to that obtained (92.8%) at Fort Indiantown Gap.

Because of the way the participating unit kept records, only eventual qualification scores were available from the prior year. In other words, soldiers failing to Q1 were permitted to refire and only the eventual score was recorded. Accordingly, prior year eventual hit scores were available for $N = 50$ soldiers, and averaged 32.74. Using data from the 50 soldiers with scores in both prior and current years, the prior year qualification hit score mean did not differ from either the current year first-run qualification hit score mean (31.96) or the current year eventual qualification hit score

mean (32.48). Based on these 50 soldiers, eventual qualification rates were 92.0% and 98.0% for the current and prior years, respectively. This proportional difference was not statistically significant.

Correlation between LMTS and live-fire ALT-C. A somewhat higher correlation occurred, $r(65) = .24$, between LMTS- and live-fire-based ALT-C scores, but it was still relatively low and nonsignificant, $p = .056$.

Conclusions and Lessons Learned

Bangor results were consistent with those obtained at Fort Indiantown Gap. Both investigations left little doubt that the LMTS-based sustainment training program was capable of supporting a realistic and comprehensive rifle marksmanship POI. The LMTS-based training program was also successful in both implementations in identifying soldiers in need of remedial training and in permitting the delivery of needed training via LMTS as part of the POI.

The two investigations, however, were less successful in demonstrating training effectiveness through the comparative success of LMTS-based training vs traditional (prior year) marksmanship training, although this problem was due at least as much to methodological deficiencies as to any shortcoming associated with LMTS itself. While it was true at Fort Indiantown Gap that implementation of the LMTS POI produced a dramatic increase in marksmanship qualification rates (from 63.6% to 92.8%), this increase could not be interpreted unambiguously because the prior year rate was based upon qualification firing on a range with pop-up targets. At Bangor, firing ranges were consistent for both years, but the prior year scores showed that 98% of soldiers had qualified. This high qualification rate was virtually impossible to improve upon. The observed dip in the marksmanship qualification rate the following year (to 92%) could easily have been the result of statistical regression, the tendency for groups with extreme scores (high or low) to regress toward the true mean on a subsequent test occasion, due to nothing more than measurement error (Campbell & Stanley, 1963).

Another consistent finding from both Fort Indiantown Gap and Bangor was the relatively low LMTS-to-live-fire relation. Both investigations produced positive but nonsignificant correlations. Only the Bangor correlation coefficient approached statistical significance, and even it was not strong enough to support useful predictions of live-fire qualification outcomes. At Fort Indiantown Gap, the relation was possibly weakened by the fact that training was conducted outdoors, but at Bangor LMTS data collection took place indoors under controlled lighting conditions, yet the strength of the relation was still only $r = .24$. With a training system (LMTS) that so unambiguously simulates the criterion measure (qualification firing), the relation between the two measures should be stronger. By all accounts, LMTS embodies a high degree of realism. Soldiers train with their own weapons. They fire at targets that are dimensionally identical to live-fire targets. Scoring procedures are identical on the simulated and live-fire ALT-Cs. With the accompanying POI, the LMTS component forms part and parcel of a high-fidelity simulated training environment. Yet, LMTS scores were not highly

correlated with live-fire qualification scores. This outcome puzzled investigators for some time, eventually prompting them to review the marksmanship training literature in search of a possible methodological explanation.

Based on findings from both Fort Indiantown Gap and Bangor, ARI investigators were satisfied that LMTS was fully capable of supporting a comprehensive and realistic marksmanship sustainment training program, but more data were needed in two areas, (1) evidence of LMTS' relative effectiveness vs alternative training methods, and (2) demonstration of a robust LMTS-to-live-fire relation. The next investigation of LMTS training effectiveness was conducted at the U.S. Army Infantry School (USAIS), Fort Benning, GA.

The Fort Benning Investigation

After hearing of ongoing work to develop an LMTS-based marksmanship sustainment training program, the USAIS became interested in testing the new technology's relative effectiveness vs current training methods on initial entry Basic Rifle Marksmanship (BRM) performance. Accordingly, ARI agreed to design and monitor an empirical test of the relative effectiveness of the two training approaches.

Three hundred eighty-six infantry trainees were divided into experimental vs control groups. All soldiers received 11 periods of BRM instruction, leading up to and including firing for qualification (i.e., record fire). Control and experimental groups received identical training during Period 1 (Introduction to BRM and Mechanical Training), Periods 4-10 (various kinds of live-fire target practice), and Period 11 (Record Fire). Control and Experimental groups differed, however, in terms of the training devices used during BRM Periods 2 and 3. The control group used the dime [washer] to practice trigger squeeze technique, the target/shadow box to practice aiming/sight picture alignment, the Multipurpose Arcade Combat Simulator (MACS) to assess the level of trainee adherence to marksmanship fundamentals, and Weaponeer to assess the subsequent application of these fundamentals during the simulated process of shot grouping.

The experimental group, in contrast, substituted LMTS for the above four devices during Periods 2-3. LMTS was used to complete three exercises (Commander, SATT, 1999a). Exercises 1 (Reflective Target) and 2 (Interactive Dry Fire) covered the development and refinement of marksmanship fundamentals, whereas Exercise 3 (Grouping and Zeroing) was devoted to shot grouping practice followed by weapon prezeroing with LMTS in preparation for subsequent live-fire grouping and zeroing during Periods 4 and 5. (See either Appendix B for a more detailed description of each exercise, or Commander, SATT [1999a] for a complete description of the LMTS-based POI.).

Trainee performance was measured in terms of the number of targets hit and/or rounds fired during live-fire Periods 4-11. In general, the results favored the experimental group during grouping, zeroing, and known distance (KD) firing (i.e.,

Periods 4-6) but showed no consistent advantage for either group thereafter. During Periods 4-5, the control group fired an average of three rounds more per trainee to achieve an acceptable shot group, and five more rounds per trainee to zero their weapons. (All cited differences were statistically significant at $p < .05$.) Moreover, a greater percentage of the experimental group successfully grouped within the specified 27-round standard and zeroed within the specified 18-round standard. The experimental group also hit more targets than the control group during KD range firing (Period 6).

The benefits of LMTS-based training, however, stopped with Period 6, which is perhaps not surprising when it is acknowledged that at this point in the BRM training program targets were switched from the stationary targets placed at known distances to the variable-distance, pop-up variety. The LMTS version used in this test did not incorporate practice with pop-up targets, and it has been suggested (Martere, Hunt, & Parish, 1987) that pop-up targets require a distinctly different set of marksmanship skills. Thus, there was little reason to expect treatment differences beyond Period 6. An LMTS pop-up target system that replicates the live-fire courses of fire is currently under evaluation by the USAR.

The Fort Benning outcome extended and complemented Fort Indiantown Gap and Bangor results. The two earlier investigations exposed troops to an experimental sustainment training method during the current year and compared their performance to earlier year results, which had been based on traditional training methods. Any observed differences between current and prior year performances might be due to the innovative training method, or they might be due to other, uncontrolled events that occurred during the intervening year. The approach used at Fort Benning, on the other hand, was more controlled. Some troops received LMTS-based training and others received traditional methods. Under this more experimentally rigorous arrangement, any observed marksmanship performance differences could be ascribed more confidently to differences in training. Thus, the predominance of research, coming from both reserve and active component soldiers, during both sustainment and initial marksmanship training, suggests that LMTS is at least as effective as traditional marksmanship training methods and superior in some respects.

Up to this point in ARI's evaluation of the LMTS-based marksmanship sustainment training program, supportive evidence had accumulated on all but one important front. Unfortunately, there was still scant evidence to support the notion of a viable LMTS-to-live-fire empirical relation, and without the ability of LMTS to predict live-fire qualification scores, the training model would be limited. Only with a viable device-based prediction tool could LMTS be used not only for sustainment training, but also to (a) identify which soldiers are in need of it (i.e., those predicted not to be unlikely live-fire qualifiers), (b) determine when enough sustainment has been provided (i.e., when successful live-fire qualification is predicted), and (c) support device-based qualification, as an alternative to live-fire qualification, when range facilities are not readily available. It was time to turn full attention to the illusive LMTS-to-live-fire relation.

The Marksmanship Training Literature Review

A review of the marksmanship training literature revealed a potential explanation for the weak correlations between LMTS and live-fire qualification scores found at Fort Indiantown Gap and Bangor. Schendel, Heller, Finley, and Hawley (1985) reported that the Weaponeer marksmanship trainer could be used to predict live-fire performance when marksmanship training was *not* provided immediately prior to Weaponeer testing. When marksmanship training immediately preceded Weaponeer testing, on the other hand, Weaponeer scores consistently (across three different test conditions) failed to predict subsequent live-fire results.

This finding could well be the result of a statistical artifact known as truncation (or restriction) of range. That is, robust correlations depend on unrestricted variances in the underlying measures. According to measurement theory, truncated distributions will reduce variance and produce attenuated correlations (Nunnally, 1967, p. 126). If two distributions of scores are robustly correlated (as one would expect to find between LMTS and live-fire scores, for instance) and the range of scores in one (or both) of these distributions is truncated, the result will be reduced variance and a byproduct of reduced variance will be a weakened coefficient of correlation. And training, such as that delivered at Fort Indiantown Gap and Bangor, is a potent cause of score truncation. In fact, that is the very purpose of training, to improve and homogenize scores, and hence to reduce variance. If training is effective, it eliminates low scores altogether while bunching the remaining scores together and forcing them toward the top of the distribution. The more effective the training, the more this truncation effect could be expected to occur. Thus, LMTS-based training, which occurred immediately prior to firing the LMTS ALT-C at both Fort Indiantown Gap and Bangor, may at least partly explain the low correlation found between LMTS and live-fire scores.

Moreover, truncation of range on the predictor (LMTS) side of the prediction equation is only half the story. Truncation of range is equally detrimental when it occurs on the outcome measure, and that is exactly what occurred naturally at both Fort Indiantown Gap and Bangor. The reader will recall that at Fort Indiantown Gap 75.9% of participating soldiers achieved Q1. That is, they fired at least 26 out of 40 possible points on their first try. At Bangor, the Q1 rate was even higher, 83.1%. These outcomes were great for purposes of demonstrating training effectiveness, but they were not so good for development of a prediction model because the juxtaposition of LMTS-based training with LMTS and live-fire ALT-Cs very likely restricted the range of both predictor and outcome (criterion) scores. When both predictor and criterion variables are truncated, the suppressive effect on coefficients of correlation is doubly pronounced.

Based on guidance derived from the literature review, the next investigation was dedicated to assessing the LMTS-to-live-fire relation. Extrapolating from the Schendel, et al. (1985) findings, optimal conditions were deemed most likely to occur when LMTS and live-fire ALT-C firings were conducted without preceding marksmanship training. A glance at Table 1 in Appendix A shows that this state of affairs was scheduled to occur in Control Group C. Accordingly, it was determined that the next data collection effort

would eliminate LMTS-based training and include only the firing of LMTS and live-fire ALT-C. By the time the next effort was scheduled, moreover, a pistol (Commander, SATT, 1999b) POI was ready for evaluation, along with its associated LMTS-based Alternate Pistol Qualification Course (APQC) (Headquarters, Department of the Army, 1988). Thus, the objective of the next investigation was to collect sufficient data to examine the predictive capability of both the LMTS ALT-C for rifle and the LMTS APQC for pistol.

The Orchard Range Rifle Investigation

Ninety-five members of an Idaho Army National Guard armor brigade voluntarily participated in this investigation as part of their yearly rifle qualification firing at Orchard Range near Boise, ID (Smith & Hagman, 2000). All participating soldiers fired M16A2 rifles.

To control for possible sequence effects[1], approximately half the soldiers fired live-fire ALT-C first, and then LMTS ALT-C. The other half fired this sequence in reverse, with no more than an hour occurring between the two firings under either sequence. Live-fire range proceedings were conducted in accordance with standard rifle marksmanship principles stipulated in FM 23-9 (Headquarters, Department of the Army, 1989). Grouping and zeroing were accomplished immediately preceding live-fire qualification trials, using standard 25m M16A2 zeroing targets. Qualification firing was conducted on 25m scaled silhouette targets (Headquarters, Department of the Army, 1989; Appendix G).

LMTS ALT-C was fired in a tent set up next to the live-fire range and followed the same procedures used for live-fire. LMTS ALT-C was fired using the dry-fire method described earlier in the Fort Indiantown Gap and Bangor investigations. Seven officers and NCOs from the 84th DIVIT and SATT supervised the conduct of LMTS-based ALT-C firing procedures, whereas target scoring was done automatically by the device.

Scores on both LMTS and live-fire ALT-C could range from 0 to 40. Twenty-six to 32 points earned a Marksman rating, 33-37 earned a Sharpshooter rating, and 38-40 points earned an Expert rating. Data were successfully cross-validated using procedures described by Tatsuoka (1969).

Results

An empirical test of the truncation hypothesis. If LMTS-based training in previous investigations really had truncated scores and caused them to cluster toward the top of their respective distributions (thereby reducing variance and limiting the strength of derived correlations), then one might expect to see a different pattern in the Orchard Range data, where marksmanship training was purposely left out. Specifically, one

[1] All potential sequence effects for both rifle and pistol (see the following section, The Orchard Range Pistol Investigation) were statistically nonsignificant ($p > .05$) and, therefore, are not mentioned further in reviewing the results.

might expect to see more variance in the Orchard Range data, proportionally fewer extreme scores, and perhaps even lower performance overall due to the absence of LMTS training prior to record fire. This possibility was not examined in the original Orchard Range report (Smith & Hagman, 2000), but for purposes of this review a meta-analysis was conducted by obtaining all three sets of original data, merging Fort Indiantown Gap and Bangor (to simplify comparisons), and then comparing the merged outcomes from Fort Indiantown Gap and Bangor with those from Orchard Range. The results are presented in Table 1.

Table 1
Evidence of Score Truncation from Fort Indiantown Gap (FIG) and Bangor vs Orchard Range on LMTS and Live-Fire ALT-C.

	LMTS ALT-C				Live-Fire ALT-C		
	FIG[1] + Bangor	Orchard Range	Diffe-rence		FIG[1] + Bangor	Orchard Range	Diffe-rence
Mean	30.74	28.54	$p = .043$		30.70	30.24	*ns*
Variance	65.29	70.56	*ns*		31.14	48.86	$p = .012$
Range	5-40	5-40	--		17-40	13-40	--
N	148	95	--		148	95	--
Q1[2]	75.8%	70.5%	*ns*		79.1%	77.9%	*ns*
Qnth[3]	--	--	--		91.9%	83.1%	$p < .05$
R	--	--	--		.24	.55	$p < .001$

FIG[1] = Fort Indiantown Gap
Q1[2] = First Round Qualification Rate
Qnth[3] = Eventual Qualification Rate

For LMTS ALT-C (the left half of Table 1), both mean score and Q1 percentages were elevated at Fort Indiantown Gap and Bangor, relative to those obtained at Orchard Range, while score variance was suppressed, a pattern consistent with the hypothesis that prior LMTS training would bunch scores toward the high end of the distribution while suppressing variance. Only the mean difference, however, was statistically significant, $F(1, 242) = 4.16, p = .043$, with the mean from Fort Indiantown Gap and Bangor significantly exceeding the Orchard Range mean. Consistent with the higher mean score, somewhat more soldiers achieved Q1 at Fort Indiantown Gap and Bangor than at Orchard Range, but the difference was not significant, $z < 1.0$. Score ranges were identical (from 5 to 40) at both sites.

Support for the truncation hypothesis was strongly evident on the live-fire ALT-C variable, as shown in the right half of Table 1. Although means did not differ significantly, the Orchard Range mean was lower, as expected. Moreover, the Orchard Range variance was significantly higher, as indicated by Levine's Test $(1, 241) = 6.39, p = .012$ for homogeneity of variance. Consistent with the greater Orchard Range score variance, scores also had a wider range (13 to 40) than at Fort Indiantown Gap and Bangor (17 to 40). The proportion of Q1 did not differ significantly, but it was in the direction consistent with the hypothesis, with a higher rate at Fort Indiantown Gap and

Bangor. Eventual qualification rates (Qnth), moreover, differed significantly, $z = 1.98$, $p < .05$, also with a higher rate observed at Fort Indiantown Gap and Bangor.

The last row in Table 1 shows the correlations between LMTS and live-fire ALT-C scores for Fort Indiantown Gap and Bangor, $r(148) = .24$, $p < .01$), and for Orchard Range, $r(95) = .55$, $p < .001$. Although both coefficients were statistically reliable, a Fisher's z-transformation (Hays, 1963, p. 530) indicated that the Orchard Range correlation of $r = .55$ significantly exceeded the Fort Indiantown Gap and Bangor correlation of $r = .24$, $z = 2.80$, $p < .01$.

The results depicted in Table 1, though far from perfect in every detail, consistently supported the truncation hypothesis. The directional outcome of every comparison was consistent with the hypothesis, and four of the eight tested comparisons were statistically reliable. Thus, the LMTS-based training that took place before LMTS and live-fire ALT-C firing at Fort Indiantown Gap and Bangor appears to have reduced score variance while bunching data toward the extremes of the distributions, as hypothesized. At Orchard Range, where LMTS-based training did not occur, score variance was higher and scores were distributed over a wider range (at least for the criterion measure), resulting in a significantly more robust correlation between LMTS and live-fire ALT-C scores.

Rifle prediction model. The relatively robust Orchard Range correlation permitted development of a least-squares regression equation (Smith & Hagman, 2000) that took the form:

$$Y = 17.16 + .46(X_1)$$

where Y = predicted live-fire score and X_1 = LMTS score. The standard error of the prediction (*SE*) was = 5.86. With this equation, marksmanship trainers can predict live-fire scores (Y) for any level of LMTS ALT-C (X_1). Moreover, trainers can also determine the level of LMTS performance associated with any desired level of live-fire performance, such as 26, the cut-point for qualification at the Marksman level. For example, a trainer might begin with the original prediction equation, substitute the desired live-fire score for its symbol (Y), and solve for the required level of LMTS:

$$\begin{gathered} Y = 17.16 + .46(X_1) \\ 26 = 17.16 + .46(X_1) \\ 8.84 = .46(X_1) \\ (X_1) = 19.22 \end{gathered}$$

Thus, soldiers with an LMTS score of 19 would, on average, be expected to obtain a record fire score of 26, the minimum score required for qualification at the Marksman level. Not all soldiers with an LMTS score of 19 would obtain a live-fire score of exactly 26, of course. Some would score lower than 26 and some would score higher, but their average score would be 26.

Live-Fire (Rifle) Prediction Tool

Smith and Hagman (2000) entered the Orchard Range data into the ARI Live-Fire Prediction Tool (Hagman, 1998; Hagman, in publication) to produce the results reproduced here in Table 2. With this table, marksmanship trainers not only can predict their soldiers' live-fire qualification scores, but also their likelihood of qualification at the Marksman, Sharpshooter, and Expert levels. As we already know from the equation above, a soldier with an LMTS score of 19 (Column 1) would be predicted to fire 26 on the live-fire range (Column 2) and have a 50% chance of successful record fire qualification at the Marksman level (Column 3). From the table, we can see that this same soldier has a 10-20% chance of qualification at the Sharpshooter level (Column 4), and less than a 10% chance of qualification at the Expert level (Column 5). As another example, a soldier with an LMTS score of 26 (Column 1) would be predicted to fire 29 on the live-fire range (Column 2) and have a 70% chance of successful record fire qualification at the Marksman level (Column 3), a 20-30% chance of qualification at the Sharpshooter level (Column 4), and less than a 10% chance of qualification at the Expert level (Column 5). And as a final example, a soldier with an LMTS score of 30 would be predicted to fire 31 on the range and have an 80% chance of qualifying Marksman, a 30-40% chance of qualifying Sharpshooter, and a 10-20% chance of qualifying Expert.

Table 2
LMTS-Based Predicted Chances of First-Run Rifle Qualification at Marksman (≥26), Sharpshooter (≥33), and Expert (≥38) levels on ALT-C.

LMTS Score	Predicted Qualification Score	Chances of a Live-Fire Score of … ≥ 26 (Marksman)	≥ 33 (Sharpshooter)	≥ 38 (Expert)
3	19	10	--	--
8	21	20	--	--
13	23	30	--	--
16	25	40	--	--
18	25	--	10	--
19	26	50	--	--
23	28	60	--	--
24	28	--	20	--
26	29	70	--	--
28	30	--	30	--
29	30	--	--	10
30	31	80	--	--
31	31	--	40	--
34	33	--	--	20
35	33	--	50	--
36	34	90	--	--
38	35	--	60	--
39	35	--	--	30

Another way of using Table 2 is to read down one of the last three columns to the desired level of qualification probability, and then across to the first column to determine the level of LMTS proficiency associated with that probability. For example, if a marksmanship trainer wants a soldier to have at least a 50% chance of record fire qualification, then an LMTS score of 19 is required. The chance of record fire qualification rises to 70% if the soldier's LMTS score is 26, and it climbs to 80% with an LMTS score of 30. Thus, for a desired level of marksmanship, a trainer can read down the respective column and then scan across to the first column to locate the level of LMTS proficiency associated with that desired level of live-fire proficiency.

The Orchard Range Pistol Investigation

Eighty-one soldiers from an Idaho Army National Guard armor brigade voluntarily participated in this investigation as part of their yearly pistol qualification firing at Orchard Range near Boise, ID. All participating soldiers fired M9 pistols. There was no cross-participation in this and the rifle investigation.

Live-fire APQC range proceedings were conducted in accordance with standard pistol marksmanship procedures stipulated in FM 23-35 (Headquarters, Department of the Army, 1988). LMTS-based APQC was fired in a tent set up next to the live-fire range and followed the same procedures used for live-fire. All LMTS-based fire was conducted in a dry-fire mode using a two-hand (fist) grip. The first round was fired double action and for each subsequent shot soldiers were instructed to use their support-hand thumb to sweep up and manually re-cock the pistol's external hammer. Seven officers and NCOs from the 84th DIVIT and SATT supervised the conduct of LMTS-based APQC firing, whereas target scoring was done automatically by the device. To control for possible sequence effects, approximately half the soldiers fired live-fire APQC first, and then LMTS APQC. The other half fired this sequence in reverse, with no more than an hour occurring between the two firings under either sequence.

Scores on both LMTS and live-fire APQCs could range from 0 to 200. Number of hits could range from 0 to 40. Qualification required a score of at least 80, plus 24 or more hits. Eighty to 119 points resulted in qualification at the Marksman level, 120-159 yielded a Sharpshooter rating, and 160-200 points were required for an Expert rating. As in the rifle investigation, pistol data were successfully cross-validated using procedures described by Tatsuoka (1969).

Results

Pistol prediction model. LMTS APQC scores ranged from 81 to 195, with a mean of 154. All 81 soldiers who fired the LMTS APQC obtained a score of at least 80, plus 24 or more hits (minimum requirements for qualification at the Marksman level). Live-fire scores ranged from 73 to 193 with a mean of 143. Seventy-six of 81 soldiers (93.8%) achieved Q1 on the live-fire APQC. Thus, even in the absence of any marksmanship training, Q1 rates were 100% for LMTS and 93.8% for live-fire, indicating that considerable truncation had occurred. The resulting correlation between LMTS and live-

fire (r = .47), although undoubtedly suppressed by the substantial degree of truncation in the data, was nonetheless significant, as revealed by a least squares regression analysis. The prediction equation took the form:

$$Y = 53.31 + .58(X_1)$$

where Y = predicted live-fire score and X_1 = LMTS score. The standard error (*SE*) was = 27.12.

As with the rifle prediction equation, the pistol equation can be used to predict live-fire APQC record scores by substituting the desired live-fire score for its symbol (Y), and solving for the required level of LMTS. Thus, the LMTS score (X_1) associated with a minimum qualification score (Y) of 80 is:

$$\begin{gathered} Y = 53.31 + .58(X_1) \\ 80 = 53.31 + .58(X_1) \\ 26.69 = .58(X_1) \\ (X_1) = 46.02 \end{gathered}$$

Thus, soldiers with an LMTS score of only 46 would, on average, obtain a record fire score of 80, the minimum required for qualification at the Marksman level. Not all soldiers with an LMTS score of 46 would obtain a live-fire score of exactly 80, of course. Some would score lower than 80 and some would score higher, but their average score would be 80.

Live-Fire (Pistol) Prediction Tool

Table 3, reproduced from Smith and Hagman (2000), was produced by the ARI Live-Fire Prediction Tool (Hagman, 1998; Hagman, in publication). For a range of LMTS scores (Column 1), this table shows predicted mean qualification scores (Column 2) and the associated probabilities (Columns 3-5) of shooting greater than or equal to 80 (Marksman), 120 (Sharpshooter), and 160 (Expert) during qualification firing. From the discussion above, we already know that a soldier with an LMTS score of 46 would be predicted to fire 80 on the live-fire range and have a 50% chance of successful record fire qualification at the Marksman level. From the table, we can see that this same soldier has a less than 10% chance of qualification at the Sharpshooter level, and a negligible chance of qualification at the Expert level. As another example, a soldier with an LMTS score of 86 would be predicted to fire 103 on the live-fire range and have an 80% chance of successful record fire qualification at the Marksman level, a 20-30% chance of qualification at the Sharpshooter level, and less than a 10% chance of qualification at the Expert level. And as a final example, a soldier with an LMTS score of 155 (approximately the average score obtained by soldiers in this investigation) would be predicted to fire 143 on the range and have a virtual certainty of qualifying Marksman, an 80% chance of qualifying Sharpshooter, and a 20-30% chance of qualifying Expert.

It must be pointed out that the usefulness of the pistol prediction tool is limited somewhat by the fact that the vast majority of soldiers in the Orchard Range study (93.8%) achieved live-fire Q1 and all of them achieved LMTS Q1. Thus, based on LMTS results, every soldier could be predicted to achieve live-fire Q1 and this blanket prediction would be correct in 93.8% of cases. From Table 3 it can be seen that even the soldier with the lowest LMTS score (81) obtained in the investigation nevertheless had a high probability (almost 80%) of successfully qualifying. From the table it can also be seen that a soldier with an LMTS score near the group average (154) would be virtually assured of live-fire qualification. Because of the unexpectedly high performance levels, LMTS scores in Column 1 of less than 86 are statistical extrapolations which go beyond the actual range of observed scores. Accordingly, marksmanship trainers should use extra caution when basing predictions on LMTS scores of less than 86. The USAR is investigating alternative LMTS courses of fire for M9 pistol to address this potential shortcoming.

Table 3.
LMTS-Based Predicted Chances of First-Run Qualification at Marksman (≥80), Sharpshooter (≥120), and Expert (≥160) Levels on APQC.

LMTS Score	Predicted Qualification Score	Chances of a Live-Fire Score of ... ≥ 80 (Marksman)	≥ 120 (Sharpshooter)	≥ 160 (Expert)
6	57	20	--	--
21	66	30	--	--
34	73	40	--	--
46	80	50	--	--
55	85	--	10	--
58	87	60	--	--
71	94	70	--	--
75	97	--	20	--
86	103	80	--	--
90	106	--	30	--
103	113	--	40	--
107	115	90	--	--
115	120	--	50	--
123	125	--	--	10
127	127	--	60	--
139	134	--	70	--
144	137	--	--	20
155	143	--	80	--
159	146	--	--	30
172	153	--	--	40
175	155	--	90	--
184	160	--	--	50
196	167	--	--	60

Prediction Tool Implementation Guidelines

Usage Implications

In contrast to the Fort Indiantown Gap and Bangor findings, results from the Orchard Range investigation established positive linear relations between simulated rifle and pistol LMTS performance and live-fire marksmanship performance. The resulting LMTS-based prediction tools (Table 2 and 3 above) give marksmanship trainers the power to predict live-fire performance for both rifle and pistol, thereby allowing them to identify soldiers with relatively greater need for remedial/sustainment training. The tools also can be used to signal when sufficient training has been provided to ensure subsequent live-fire qualification. Moreover, the prediction tools also establish device-based, live-fire performance standards that will enable the substitution of LMTS-based qualification for live-fire qualification when outdoor range facilities are not readily available. Finally, the prediction tools can form the basis for competency-based delivery of the USAR's newly developed rifle and pistol marksmanship POIs.

Prediction Tool Implementation

Figure 3, reproduced from Smith and Hagman (2000), shows in flowchart format how a competency-based delivery approach might work. Soldiers would first be pretested by firing LMTS ALT-C (for rifle) or LMTS APQC (for pistol). Based on this outcome, soldiers would receive either a "Go" or "NoGo" depending upon whether they met or exceeded a pre-established cutoff score. Say, for instance, that the LMTS-based cutoff score was 30, the score associated with an 80% probability of live-fire Q1 at the Marksman level for rifle, or at 86, the score associated with an 80% probability of live-fire qualification at the Marksman level for pistol. Soldiers firing at or above these cutoff scores would receive a Go and be considered device-qualified. Soldiers firing below the cutoffs would be identified as needing remediation (to be delivered via the USAR's LMTS-based rifle or pistol sustainment training POI). Thus, remediation would be provided only to those in need of it, thereby, making the most of valuable training time while saving range time and ammunition in the process. Those completing remediation would then be posttest on the LMTS rifle or pistol device. Those receiving a Go on the posttest would be considered device-qualified, whereas those receiving a NoGo would undergo further remediation until they are able to meet the posttest cutoff score and its associated live-fire expectancy standard of 80% probability of live-fire qualification.

A substantial body of research and other documentation has accumulated regarding the use of LMTS as the centerpiece of a device-based marksmanship sustainment training program (BeamHit™, 1999; Commander, SATT, 1999a, 1999b, Hagman, 2000; Hagman, in publication; Hagman & Smith, 1999; Smith, 2000; Smith & Hagman, 2000) suitable for implementation in indoor and carefully controlled outdoor settings. A systematic review and assessment of this material has identified four global objectives of the USAR's LMTS-based marksmanship training program. This section lists these objectives and, based on all extant evidence, briefly evaluates the extent to which each

objective has been met, identifies remaining information deficiencies, and makes recommendations, when appropriate, for future research.

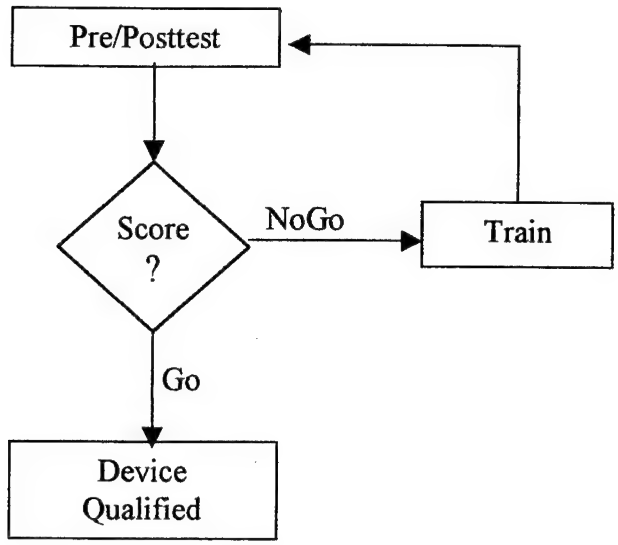

Figure 3. Flowchart of recommended delivery strategy

Conclusions and Recommendations

Support a Realistic and Comprehensive Marksmanship POI While Reinforcing Marksmanship Fundamentals

Rifle POI. Based on successful field implementations at both Fort Indiantown Gap and Bangor, LMTS has demonstrated its ability to support a realistic and comprehensive marksmanship POI while reinforcing marksmanship fundamentals. The POI that was implemented in both these locations was designed to correlate closely with FM 23-9 guidelines, and in both field tests it appears to have succeeded. Face validity and perceived realism of the LMTS-based training program was supported by the fact that soldiers used their actual weapons during training.

The only area where realism seemed to be compromised to any extent was in the use of dry firing during LMTS training and testing. In dry firing, a soldier is required to manually recock the weapon after each round by recycling the charging handle, located at the rear of the upper receiver assembly. This is a simple and easy step for the soldier to accomplish, requiring a charging handle movement of only slightly more than an inch, but it does introduce a minor variation from the semiautomatic mode of fire that is used on live-fire ranges.

The semiautomatic mode of operation, as well as nearly 100% felt recoil and 50% sound simulation, can be achieved with the LMTS system by use of an enhancement known as the M16 Blazer upper receiver group (Commander, Small Arms Training Team, 1999a). The Blazer, dimensionally identical in weight and balance to the standard-issue M16 upper receiver, attaches to the lower receiver group of the soldier's

own service weapon and allows full functionality of the bolt and ejector assemblies, thereby allowing realistic simulation of the semi-automatic mode of fire, including ammunition cycling, spent shell ejection, and sound and recoil simulation.

Blazer upper receiver groups were tested at both Fort Indiantown Gap and Orchard Range, but feeding malfunctions at the former site and incompatibility with available lasers at the latter precluded their formal evaluation. Because these feeding malfunctions and Blazer/laser incompatibilities have since been resolved, the Blazer units should be tested again against the dry firing method to see if the changes significantly augment the strength of the LMTS-to-live-fire relation.

Pistol POI. Although the pistol POI has not been formally evaluated, there is every reason to expect that it will be as successful as the rifle POI. Like its rifle counterpart, the pistol POI was designed to closely correspond to stipulated FM23-35 (Headquarters, Department of the Army, 1988) procedures. Perhaps the biggest concern with the pistol POI is not whether it will work, but whether it is needed at all, since 93.8% of soldiers at Orchard Range achieved live-fire Q1 without any marksmanship training. Because of the unexpectedly high Q1 levels at Orchard, a replication of the pistol investigation is recommended.

Identify Soldiers in Need of Remediation and Deliver Remediation As Part of the POI

At both Fort Indiantown Gap and Bangor, a definite strength of LMTS was its ability to identify soldiers in need of remedial training, remove them from the ongoing training process without interrupting the delivery of training to other soldiers, provide the needed remediation, and then return remediated soldiers to the appropriate point in the ongoing POI. At Fort Indiantown Gap, almost two-thirds of all participating soldiers were provided at least one remedial training session as part of the LMTS POI. At Bangor, this proportion grew to over 84%. Moreover, in both investigations, empirical evidence suggested that the remediation procedures worked. Both of these investigations, of course, were concerned with rifle marksmanship. The pistol POI has not been formally evaluated in this regard.

Training Effectiveness: Deliver Equal or Superior Marksmanship Sustainment Training

The empirical evidence for training effectiveness was inconclusive. Fort Indiantown Gap provided partial substantiation of the new technology's effectiveness by comparing qualification rates under LMTS with prior year rates, but the evidence was inconclusive because different kinds of firing ranges were used in the two years, and also because individual soldier scores were not available from the prior year. At Bangor, prior year individual soldier scores were available, and firing ranges were consistent for both years, but a prior year ceiling effect precluded any improvement in training effectiveness.

The Fort Benning investigation provided a side-by-side comparison of LMTS vs alternative marksmanship training methods. This comparison indicated favorable results for LMTS, at least through early stages of BRM training.

More data are needed, both from experimental comparisons and from before/after investigative paradigms, before the question of LMTS training effectiveness can be answered definitively. In order to address the research issues that arose at Fort Benning, a version of LMTS with variable distance pop-up targets is currently under development.

Develop an LMTS ALT-C and an LMTS APQC That Will:

Allow practice qualification firing with electronic targets and laser beam bullets. This objective has been met with the rifle version of LMTS, although it is possible that the current system might be improved through use of Blazer technology to further enhance training realism. Practice firing is also possible with the pistol LMTS, but one has to question whether it is needed when 100% of Orchard Range soldiers achieved LMTS APQC Q1 and 93.8% achieved live-fire APQC Q1 without benefit of any sustainment training whatsoever. More research is needed to determine if the unexpectedly high scores and Q1 rates from Orchard were anomalous. If these high scores and Q1 rates are replicated, serious attention should be given to a substantial upward revision of APQC performance standards.

Identify soldiers most in need of training and signal when enough training has been delivered by predicting subsequent live-fire scores. Both these objectives are now possible given the prediction equations developed from Orchard Range data and the prediction tools presented in Tables 2 and 3 above. In order to ensure that the best possible prediction tool is in use, it would be desirable to retest the predictive power of the LMTS ALT-C with data collected from Blazer-equipped rifles, using the Orchard investigative paradigm where no marksmanship training is imposed prior to LMTS and live-fire marksmanship skills assessment. Also, the pistol prediction model should be verified due to the unexpectedly high Q1 rates obtained at Orchard Range.

Permit LMTS-based qualification when live-fire ranges are unavailable. The rifle and pistol prediction tools also provide empirically derived sets of marksmanship performance probabilities for use in determining live-fire qualification standards on LMTS. Such standards, in the form of cutoff scores, would be required to support a decision to use LMTS scores in lieu of live-fire scores for purposes of yearly qualification. It might be decided, for example, that for soldiers to receive a live-fire qualification rating of Marksman, they must shoot an LMTS ALT-C (for rifle), or LMTS APQC (for pistol), score associated with a predicted 80% probability of successful qualification on the range (i.e., 30 for rifle; 86 for pistol). Analogous standards could also be set for Sharpshooter and Expert for each weapon.

As indicated in this section, considerable research remains to be done, but recommendations for additional research do not in any way detract from the significance of past efforts. Rather, an empirical foundation has now been laid that merits further efforts, in order to produce the best possible product. Moreover, with workable prediction tools now available for implementation, and with empirically derived live-fire performance standards serving as the basis of these tools, the USAR has taken a

substantial step forward in its commitment to meeting the Total Army readiness challenge through more productive home-station small arms marksmanship training and evaluation, while saving precious time and ammunition in the process.

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Appendix A

Overall Research Design

The overall design, consisting of three experimental and three control groups, is depicted in Table 1. The first feature of Table 1 that will catch the reader's attention is that soldiers in the first cell will fire the LMTS Alt-C using their own weapon while soldiers in the second cells will use something called the Blazer. This requires an explanation.

Table 1.
Data Collection Design (Acquisition and Prediction Phase).

Group	Training	LMTS Alt-C[1]	Record Fire Alt-C[2]
Exp 1	LMTS	Own Weapon	Live Fire
Exp 2	LMTS	Blazer	Live Fire
Exp 3	LMTS	-------	Live Fire
Control 1	Traditional[3]	-------	Live Fire
Control 2	-------	-------	Live Fire
Control 3	-------	Own Weapon	Live Fire

[1]To include prior grouping and zeroing with LMTS
[2]To include prior live-fire grouping and zeroing
[3]Based on FM23-1

In normal operation with live ammunition, the M16 rifle is a gas-operated weapon, which means that each time the weapon is fired, part of the gases emitted by the spent cartridge is harnessed for the purpose of extracting the spent shell, recocking the weapon, and chambering a new round. In this manner, each succeeding round is fired with no effort from the shooter other than successive pulls of the trigger. An LMTS-equipped M16, however, has a mandrel and laser transmitter inserted into the end of the barrel, precluding the use of any kind of ammunition (including blanks) unless the weapon's receiver unit is modified. Because the carrier bolt is not automatically recycled by escaping gas on an LMTS-equipped weapon, the soldier is required to manually re-cock the weapon after each round by recycling the charging handle, located at the rear of the upper receiver assembly. This is a simple and easy step for the soldier to accomplish, requiring a charging handle movement of only slightly more than an inch, but it does introduce a minor variation from the semi-automatic mode of fire that is used on live-fire ranges.

The semiautomatic mode of operation, as well as nearly 100% felt recoil and 50% sound simulation, can be achieved with the LMTS system by use of the M16 Blazer upper receiver group (Commander, SATT, 1999a). The Blazer, dimensionally identical in weight and balance to the standard-issue M16 upper receiver, attaches to the lower receiver group of the soldier's own service weapon and allows full functionality of the bolt and ejector assemblies, thereby allowing realistic simulation of the semi-automatic mode of fire while maintaining familiar trigger take up and stock weld characteristics. Blazer ammunition is loaded via service magazines, thereby adding other elements of realism to LMTS-based marksmanship training through magazine changes (a mandatory component of live-fire qualification) and the experience of spent shell ejection.

Thus, the only difference between the first two experimental groups is that Group 1 is scheduled to fire the LMTS Alt-C with their own weapons while Group 2 soldiers will fire the LMTS Alt-C with Blazer-equipped weapons. A comparison of these two experimental groups will indicate the relative importance of Blazer-imparted simulation enhancements.

All three experimental groups receive LMTS training, and they will be compared to the three control groups (collectively and individually) to determine the impact of LMTS training on subsequent live-fire qualification scores. Notice, however, that only the first two experimental groups fire the LMTS Alt-C. LMTS Alt-C closely mimics live-fire Alt-C, including the use of a dimensionally identical target array, identical firing distances, scoring procedures, number of allotted rounds, firing positions, and time limits. The LMTS Alt-C ordinarily occurs immediately following conclusion of formal LMTS training. No actual training occurs during administration of the LMTS Alt-C, but it is possible, since it so closely simulates live-fire conditions, that it may have a positive effect on subsequent live-fire performance. A comparison between the first two experimental groups (which receives LMTS-Alt-C) and experimental Group 3 (which receives the formal LMTS POI but not LMTS Alt-C) will permit a determination of the relative importance of firing the simulated alternate qualification course prior to attempting actual live-fire qualification. If LMTS Alt-C proves to be a critical training element, its relative importance can be assessed by comparing the third experimental group with the third control group, which undergoes the LMTS Alt-C but without benefit of the LMTS training program. This will allow a test of the relative importance of LMTS Alt-C vs the formal LMTS training components. This would provide a first approximation toward determination of the minimum amount of LMTS training needed in order to impact live-fire qualification scores.

Comparisons of LMTS absolute training effectiveness will consist of comparing the experimental groups (separately or combined, depending upon whether any differences exist among them) with control Group 2. This can be considered a determination of absolute training effectiveness because all three experimental groups receive LMTS training, but control Group 2 receives no training of any kind. Relative training effectiveness will be determined by comparing the experimental groups with control Group 1, which receives traditional (as specified in FM 23-9) marksmanship training. If

the three experimental treatments are comparably effective, then the groups can be combined for the relative and absolute comparisons.

For all groups in the design, the plan is to collect prior year live-fire Alt-C scores. These scores will be used to evaluate the pre-training equivalency of experimental and control groups, and possibly to make statistical adjustments on outcome scores (live-fire Alt-C scores) in the event that the groups are not equivalent. For the experimental groups, prior year scores also will be used on a within-groups basis to evaluate performance before and after the experimental LMTS training.

As a test of retention, a 12-mo no-practice interval will be imposed on all groups, experimental and control, following collection of live-fire Alt-C scores. At the end of 12 mo, experimental groups 1 and 2 will again be administered the LMTS Alt-C, under own weapon and Blazer test conditions, respectively, and then all five groups will undergo a second live-fire Alt-C. The null hypothesis is that after a 12 mo no-practice interval, experimental and control groups will demonstrate equivalent retention. The alternative hypothesis is that experimental groups, having benefited from LMTS training, will exhibit less forgetting and an associated reduction in the need for sustainment training after the 12-mo no-practice interval.

At the conclusion of the investigation, the objective is to have approximately $N = 200$ soldiers in each of the five rows shown in Table 1. Because of the scope of the study, however, it is not possible to collect all the data simultaneously. The study will be conducted in stages, through a coordinated sequence of data collection occasions, making use of available reserve units as they become available for participation. Both the Fort Indiantown Gap and Bangor data collections, for example, were part of Experimental Group 1, which means that all participants received LMTS training, used their own weapons for the LMTS Alt-C component using the dry-firing method, and then went to a range for live-fire qualification trials. The Orchard Firing Range data, on the other hand, were part of Control Group 3. All participating soldiers completed both the LMTS and live-fire Alt-C's, but otherwise received no other LMTS training. (The investigations conducted at Fort McClelland and Fort Benning were not part of the overall research design.)

Appendix B

The LMTS Program of Instruction (POI)

The current LMTS POI (Commander, Small Arms Training Team, 1999) will eventually serve as one part of a comprehensive LMTS Sustainment Skills Training Package (SSTP) designed specifically for the time-constrained Reserve Component (RC) environment. Once completed, the SSTP will: (1) teach soldiers the fundamental elements of rifle marksmanship, (2) increase a soldier's confidence in the ability to use his or her service weapon, and (3) afford more practice opportunities prior to record fire qualification, especially in the range-limited constraints often presented by RC training environments.

The POI is closely correlated with FM 23-9 task requirements (Headquarters, 1989), including M16A2 weapon familiarity drills, immediate-action procedures, loading and unloading magazines, front and rear sight adjustments, application of the four fundamentals of marksmanship (steady position, aiming, breath control, and trigger squeeze), battlesight zeroing, and detecting and engaging a variety of targets (to be described in more detail below) including a timed record fire engagement using laser-equipped weapons and laser-sensitive targets. Remedial training is provided on an as-needed basis as part of the POI.

Although LMTS training is conducted in the dry-fire mode, soldiers adhere to standard live-fire range commands and weapon safety procedures throughout the training. Safety is consistently reinforced. The POI begins with a safety briefing and safety is emphasized as the most important consideration throughout the training. Soldiers are trained to make on-the-spot corrections for any observed unsafe acts, including calling a cease fire when injury or property damage might otherwise result. Additionally, soldiers are briefed on the potential visual hazards attendant to laser technology and specifically instructed never to look directly into any laser-emitting device.

Preliminary training on safety, weapon maintenance, and the four fundamentals of rifle marksmanship is conducted in a series of small group lecture-demonstration sessions. Primary training, held on simulated firing lines, consists of a sequence of progressively more complex target engagement exercises.

Target Engagement Exercise 1: Reflective Targets

This exercise is designed to test a soldier's ability to apply the four fundamentals of marksmanship. The soldier assumes the prone supported position (employing sandbags) and, using his own service weapon equipped with an LMTS laser insert, fires at an LMTS Reflective Zero Target (RZT). The RZT is an actual size representation of the Army standard 15/25m zeroing target (Figure 1-B). The LMTS RZT, however, enables an instructor to view, at 25m, laser impacts from soldiers' weapons, and thereby provide to the soldier immediate feedback concerning the adequacy with which he has positioned his body in the prone supported position, attained proper sight alignment, maintained

breathing control, and implemented proper trigger squeeze procedures. The four fundamentals can be evaluated with the laser device in constant ON position, or in training mode, where a single laser beam is emitted following each trigger pull.

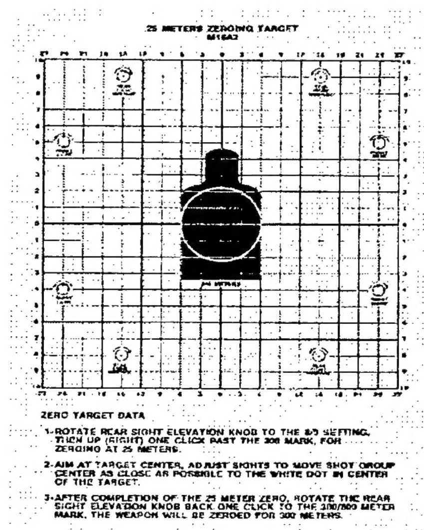

Figure 1-B. The 25m M16A2 zeroing target.

Target Engagement Exercise 2: Interactive Dry Fire

This exercise is also fired from the prone supported position, but the target is changed from an RZT to a laser-sensitive LMTS TR-700 (Figure 2-B), capable of detecting and counting the number of laser hits and misses and sending back a visual and auditory signal to the firer.

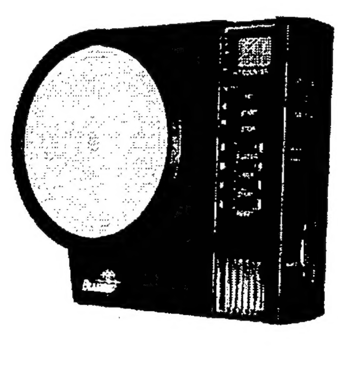

Figure 2-B. LMTS TR-700 target.

Soldiers fire at the target in sets of 10 rounds, and 8 hits out of 10 rounds are required for a "pass." The POI is designed to require at least two repetitions of the 8 out of 10 requirement, but any number of repetitions can be required, and a Military Mask

Set of silhouettes can be superimposed on the target to reduce the targeting area and thereby simulate targets at distances of up to 600m.

Following each set of 10 rounds, an instructor inspects the target and evaluates the number and pattern of hits. If the number of hits is less than 8, the instructor performs a visual laser/sight alignment check, reconfirms the soldier's understanding of the four fundamentals of rifle marksmanship, and directs the soldier to fire another set of 10 rounds. If the number of hits is less than 8 after several tries, the soldier leaves the interactive dry firing range and goes to a remedial station.

Target Engagement Exercise 3: LMTS Grouping and Zeroing

For this exercise soldiers again fire from a prone supported position using their own weapons equipped with a laser insert. Targets are computer-supported LMTS TR-900 laser-sensitive devices (Figure 3-B) with superimposed 25m silhouettes that dimensionally replicate the 25m zeroing target (Figure 1-B). The computer linked to Exercise 3 targets is loaded with software that detects the precise point of impact of each laser round and calculates center of mass and maximum dispersion of each shot group.

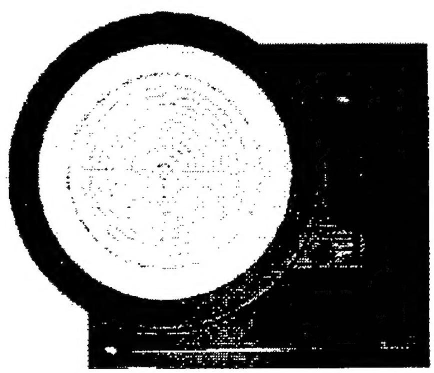

Figure 3-B. LMTS TR-900 target.

In the grouping phase of the exercise, soldiers may fire up to 27 rounds in 3-round shot groups. Satisfactory grouping is demonstrated when two consecutive 3-round shot groups (measured separately) fall within a 4cm circle. If a soldier is unable to achieve this standard within 27 rounds, he is sent to a remedial station and then is permitted to return subsequently to start anew on the grouping exercise.

Once satisfactory grouping is demonstrated, the soldier adjusts his sights to bring shot placement within the (center) 4cm circle on the 25m zeroing target. The soldier fires 3-round shot groups (up to a maximum of 18 rounds), adjusting sights as necessary between groups. When a shot group falls within the 4cm circle, the soldier fires an additional shot group for confirmation. Zeroing is satisfactorily demonstrated when a minimum of five rounds in two consecutive 3-round groups fall within the 4cm circle.

Remedial Training

Remedial training, consisting of a systematic check on the soldier's ability to apply the four fundamentals of marksmanship to the integrated act of firing an M16A2 rifle, begins with a careful weapons serviceability check and proceeds to an evaluation of the soldier's prone supported and unsupported firing positions, sight alignment picture, trigger squeeze technique, and use of proper breath control. Once the remediation instructor is satisfied that the soldier understands the four fundamentals, the soldier is directed to demonstrate their application using RZT's as described above in Exercise 1. Once the soldier properly performs the four fundamentals using RZT's, the instructor then explains how the fundamentals are integrated into the act of firing.

Depending on the judgment of the instructor, the soldier may then be re-entered into the formal POI at Exercise 2 (Interactive Dry Fire), or at either the grouping or zeroing phase of Exercise 3. Theoretically, soldiers may be pulled from the formal POI sequence any number of times, although the evaluative and corrective procedure is designed to produce problem recognition and remediation in one coordinated session.

Target Engagement Exercise 4: Simulated Qualification: The 25m Alternate Course C (LMTS Alt-C)

A properly zeroed weapon is the prerequisite for this exercise (see grouping and zeroing procedures in Exercise 3 above). Soldiers fire from prone supported and unsupported positions using their own weapons equipped with a laser insert. The target consists of an electronic Alt "C" Target System, which presents an array of 10 scaled silhouettes, ranging from 50m to 300m. This target dimensionally replicates the 25m live-fire Scaled Alternate Course qualification target (Headquarters, 1989; Appendix G.) Soldiers fire two (laser) rounds at each silhouette from a supported position (20 rounds), followed by two rounds at each silhouette from an unsupported position, for a total of 40 rounds. The target array is linked to a computer, which counts and records the number of laser hits on each silhouette. Twenty-six or more hits result in qualification at the Marksmanship level. Sharpshooter status is achieved with 33 or more hits, and 38 or more hits merit an Expert rating.